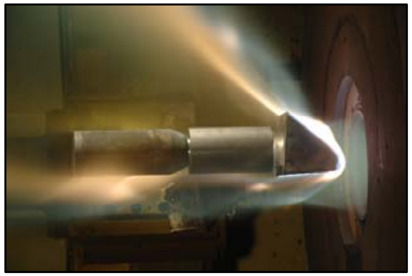
Hypersonic Materials and Structures

Fundamental Aeronautics Program
1st Annual Meeting



New Orleans, Louisiana
October 30 – November 1, 2007

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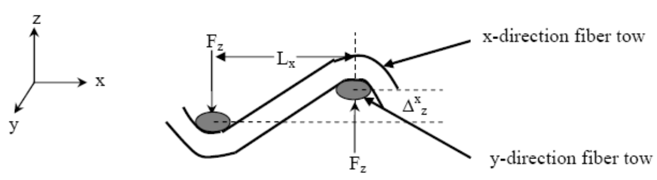
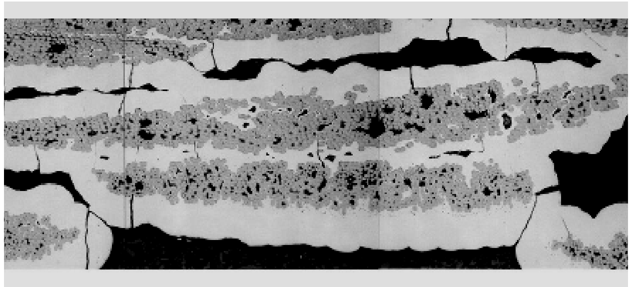




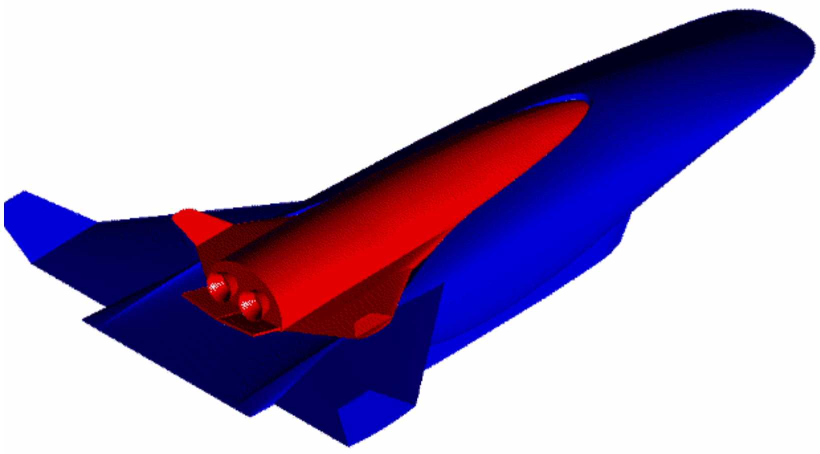
Outline

1. Materials and Structures Focus
2. Discipline Overview
3. Discipline Organization
4. Discipline Roadmap
5. Technical Elements

Hypersonic Materials and Structures Focus

Highly Reliable Reusable Launch Systems

HRRLS Materials & Structures
- Integrated Analysis Methods
- Thermal Protection Systems
- Hot Structures
- Scramjet materials/structures
- Advanced Structural Concepts



High Mass Mars Entry Systems

HMMES Materials & Structures
- High Fidelity Ablation Models
- Advanced lightweight ablators
- Hot structures
- Low-mass TPS for backshells
- Deployable decelerator materials

Discipline Objective

Materials and Structures Discipline

Advance fundamental understanding of key hypersonic high temperature materials from the atomic, constituent, test coupon, and structural application to reduce weight and increase reliability.

Top Technical Challenges

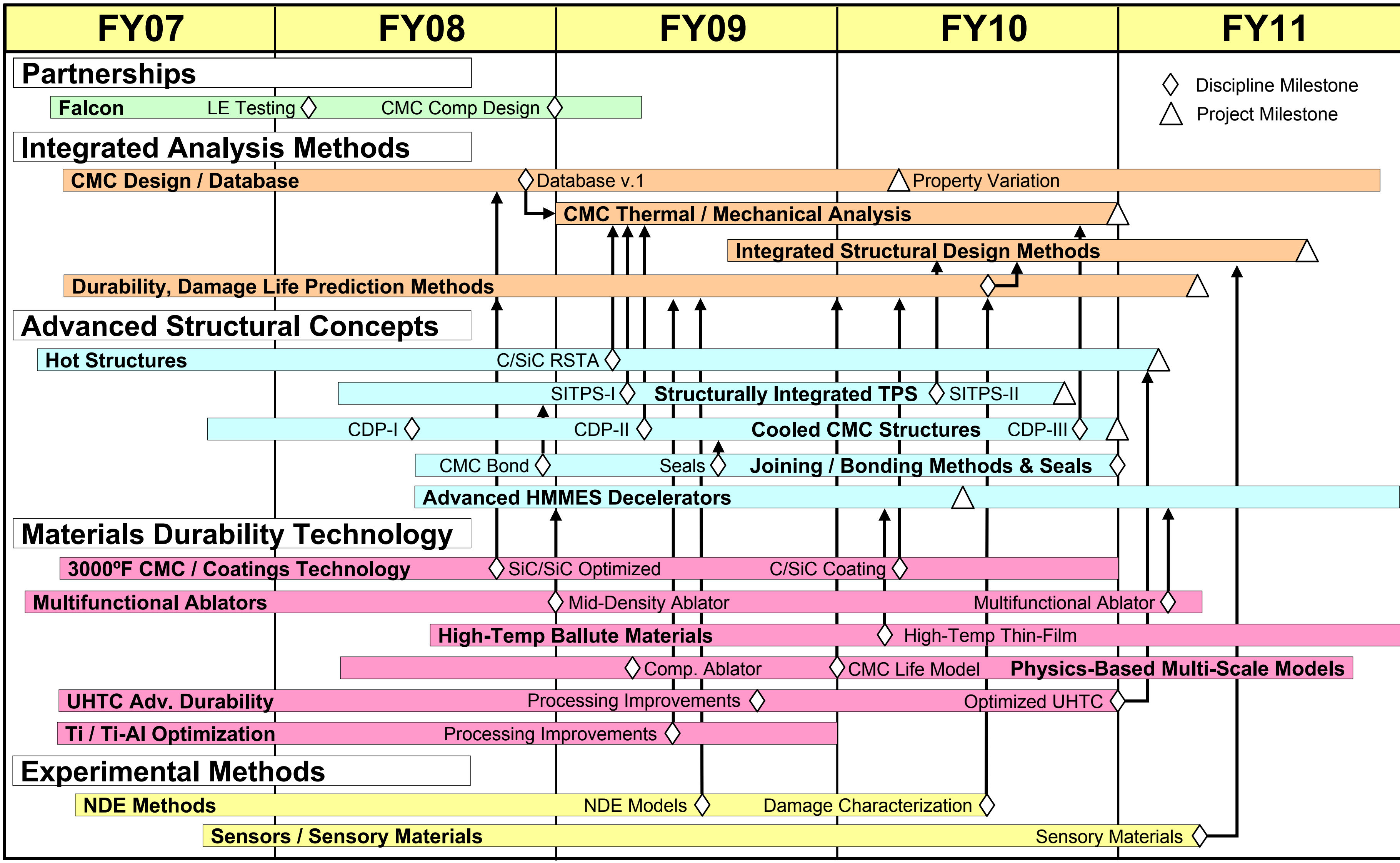
1. Advanced Structural Concepts
2. Enhanced Material Performance Limits
3. Material Durability and Life Assessment Tools
4. Integrated Analysis Methods

Discipline Organization

Technical Elements

- Partnerships
- Integrated Structural Analysis Methods
- Advanced Structural Concepts
- Durability Technology
- Experimental Methods
- NRA Awards

Materials and Structures Long Range Roadmap

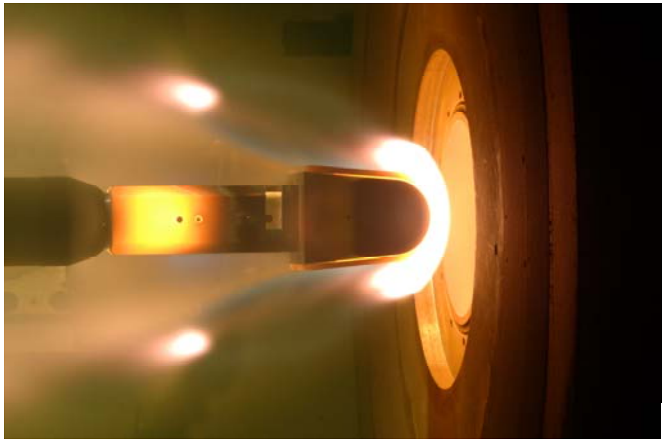


Partnerships

Falcon Materials IPT

Objectives:

- Lead Materials IPT for the DARPA/AF Falcon program.
- Coordinate and lead arc-jet and insulation testing for the HTV-2 and HTV-3X flight vehicles.
- Evaluate and characterize refractory composite materials for high temperature applications.
- Assist preliminary design requirements for a CMC nozzle.



Leading edge test article during arc-jet testing at AEDC

PAI-DAE

Integrated Analysis Methods

Technical Challenge

Materials and structures analysis integration with MDAO methods requires reduced computational time without sacrificing in analysis fidelity.

State-of-Art

COTS software for thermal/structural analysis allow sophisticated material models, but do not predict or account for degradation. Reduced-order models for thermal analysis do not exist and are in their infancy for structural analysis.

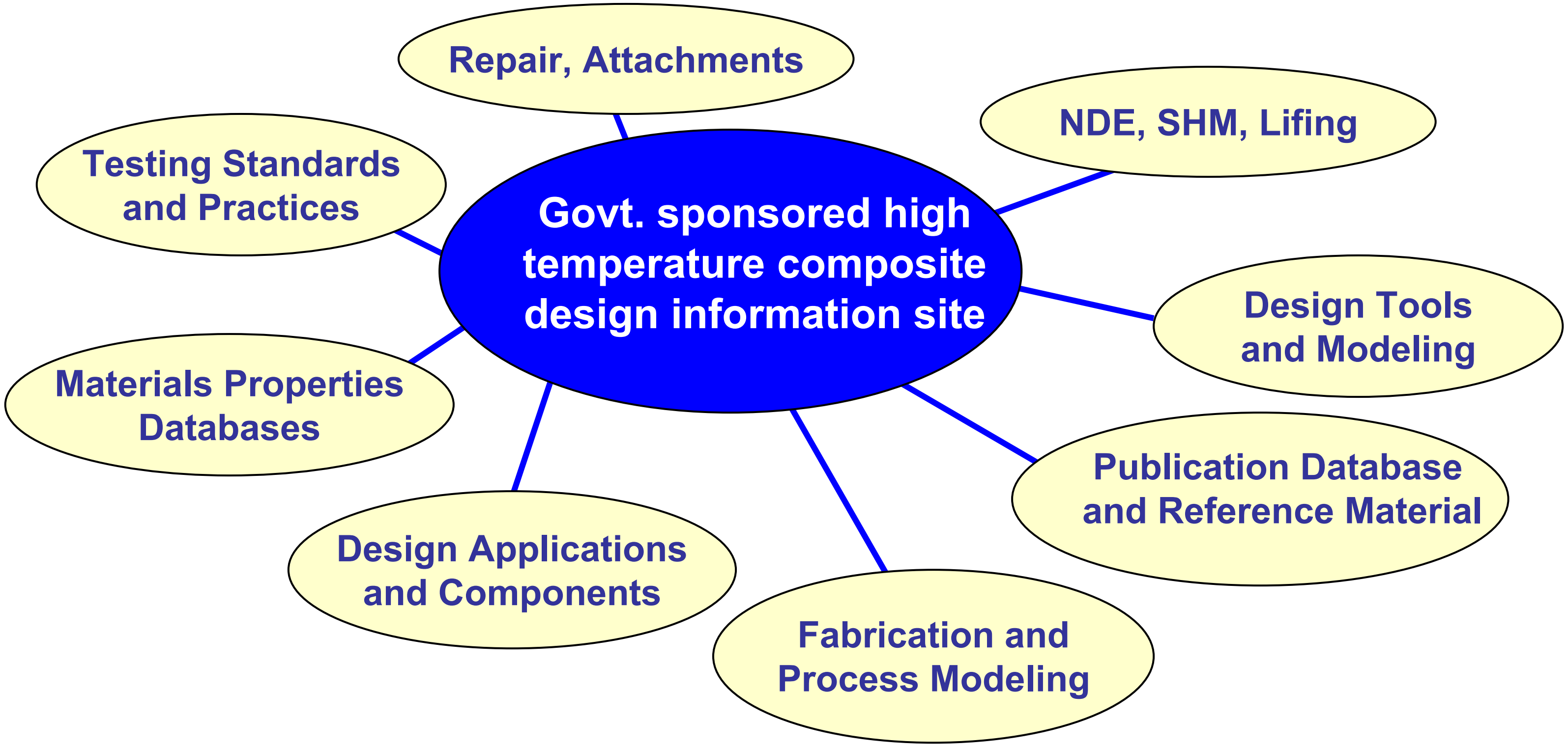
Approach

Develop integrated thermal-structural optimization methods for hot structures and structurally-integrated TPS. Develop and validate reduced-order models for nonlinear dynamic structural response for thermal acoustic fatigue predictions.

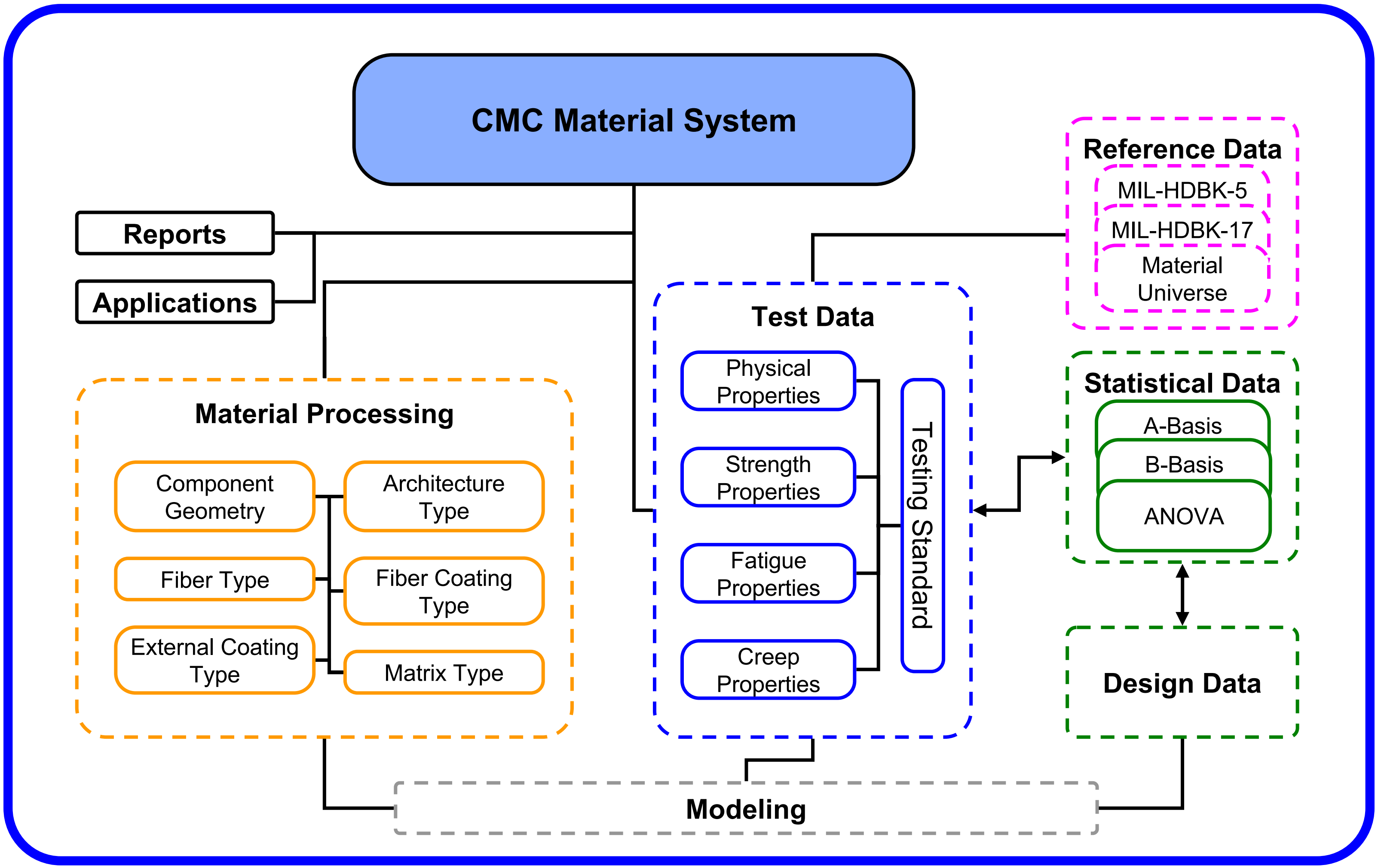
Design Database

Database activity is in the planning stage

- Software architecture nearly defined
- Subject elements have been identified
- Computer hardware specified



NASA Database Schema



Improved Life Modeling

Material Durability, Life Prediction, and Damage Tolerance Modeling

Validated Life Prediction Methods

Validated NDE techniques or life prediction
Engineering relationships between damage and performance

Probabilistic Methods for CMC Life Prediction

Establish structural design reliability analysis methods
Uncertainty models that incorporate material property scatter

Damage Modeling and NDE

NDE techniques developed to quantify damage
Characterize relationship between NDE and microstructure

Durability and Life Prediction Modeling

Physics-based models for remaining life
Combined environment/mechanical damage interaction models

Material Durability and Damage Data

CMC design database established
Assemble database and identify technology gaps

Refractory composite development focused on C/SiC and SiC/SiC applications to propulsion, airframe and advanced EDL architectures.

Advanced Structural Concepts

Technical Challenge

Increased performance demand for weight and volume efficiency minimizes design reserve.

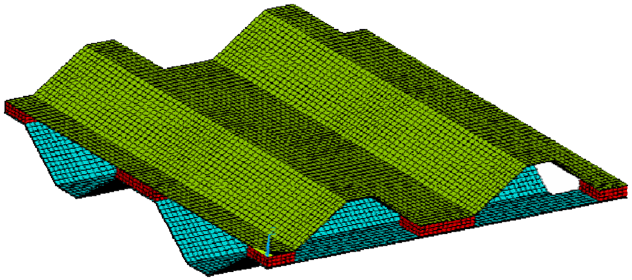
Emphasizes need for integrated, multifunctional design solutions at material and structural level.

Multiple structural requirements met by single-component single-function design solutions.

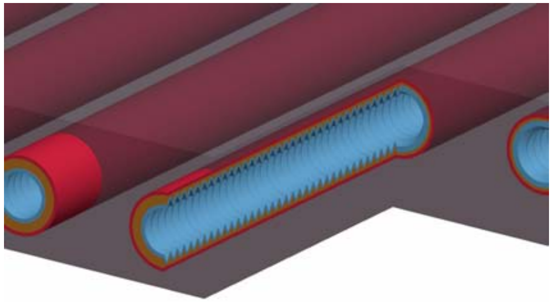
These solutions have proved to be adequate to close on a design given sufficient margins for increased structural weight.

Objectives:

- Develop and test advanced hypersonic airframe and propulsion structural concepts for reduced weight reusable vehicle components.
- Assess performance of vehicle leading-edge, acreage, and control surface structures. Advance current state of art for actively-cooled high temperature structures.
- Foster development of bonding and joining technology for high temperature materials.



Advanced Thermal Protection Systems and Materials



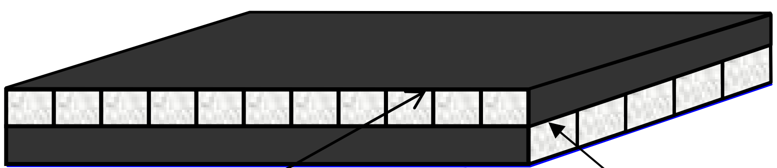
Lightweight Actively Cooled Structures

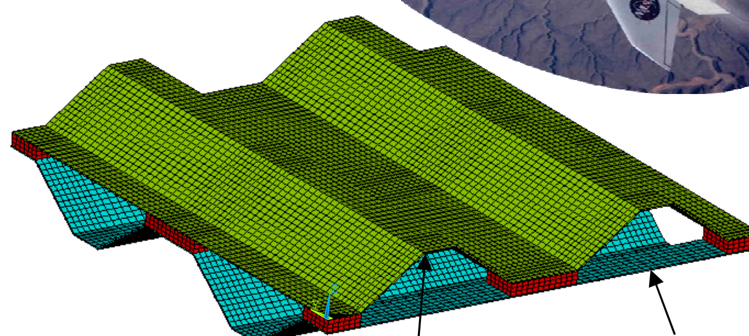
Thermal Protection System

Structurally Integrated Thermal Protection System (SITPS)

Technical Requirement
The large airframe acreage of HRRLS vehicles require lightweight structural solutions that are thermally and structurally efficient.

Technical Challenge
Concept must accommodate thermally induced strains, demonstrate to be environmentally and mechanically durable, and be capable of sustained periods of heat soak.

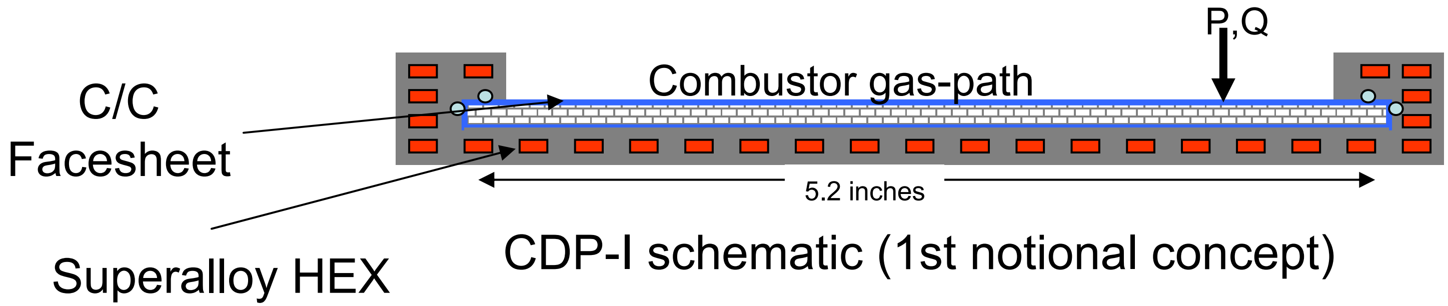




Multifunctional concept leading to system design tools for combined thermal/structural functions

Actively-cooled combustor wall

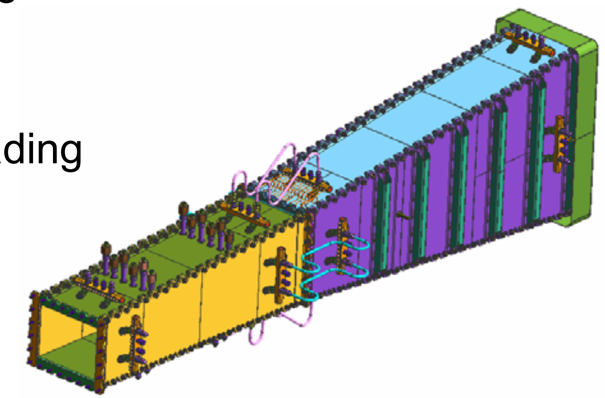
Composite Demonstration Panel (CDP-I)



CDP-I schematic (1st notional concept)

CDP-I Risk Items

- Thermal Loading
  - Top surface protected by C/C face sheet in intimate contact
- Structural Concern items
  - HCF and panel modal interaction from acoustic loading
  - Durability cycle-life estimation
  - Attachment technology
  - Surface roughness effects
- Additional Items (Material Specific)
  - Composite/surface durability (protective coating/matrix/inhibitors)



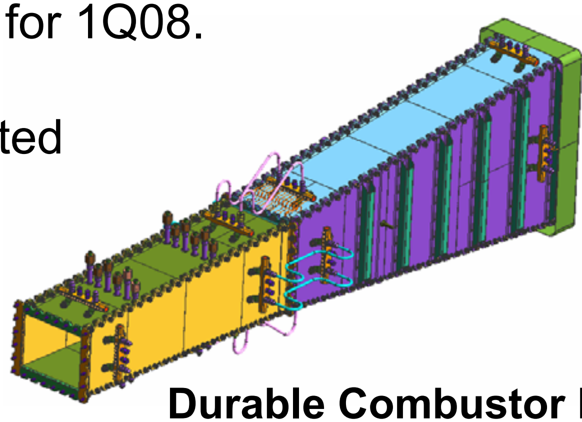
Durable Combustor Rig

CDP-II Study

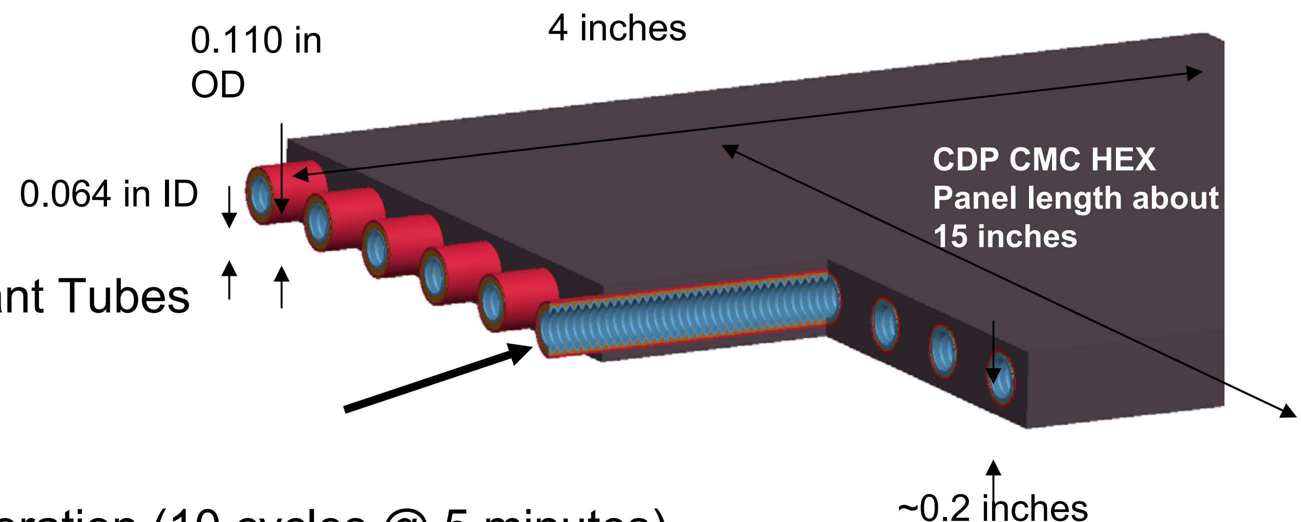
CDP-I is in the process of being fabricated. Panel delivery is scheduled for 3Q07. Panel testing is scheduled for 1Q08.

CDP-II Phase I Fabrication activity has been started

NASA:	Panel fabrication requirements
ATK/GASL:	System design requirements
Hypertherm:	Ceramic composite fabricator
Team:	Fiber architecture preform



Durable Combustor Rig



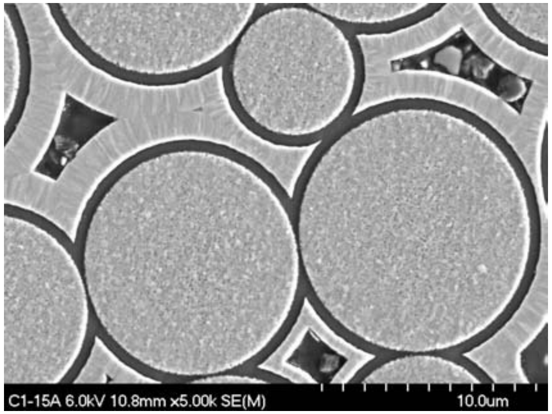
Goals: Fuel Coolant Tubes

- H2 gas
- 2000 psi
- 2000 F
- Multiple cycle operation (10 cycles @ 5 minutes)
- Impermeable to Hydrogen

Materials Durability Technology

<u>Objectives:</u>

- Advance fundamental understanding of key hypersonic high performance materials at the atomic, constituent, and test coupon level to improve the high temperature performance of enabling hypersonic materials.
- Develop and validate physics-based durability, and life prediction models for key enabling hypersonic materials.



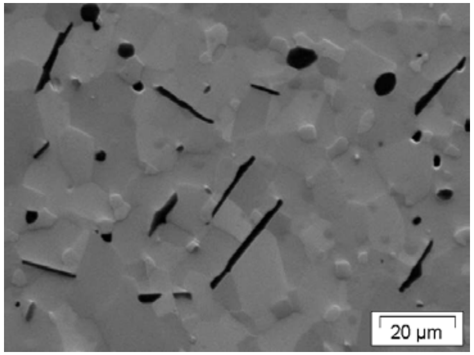
3000ºF composite development.

Technical Challenge

Reduce design margins through improved materials, material lifing data and models that reduce vehicle weight.

Guide physics-based durability modeling approach through well defined fundamental experimental studies and results.

PICA mid density variant arc jet models.



Optimized UHTC materials

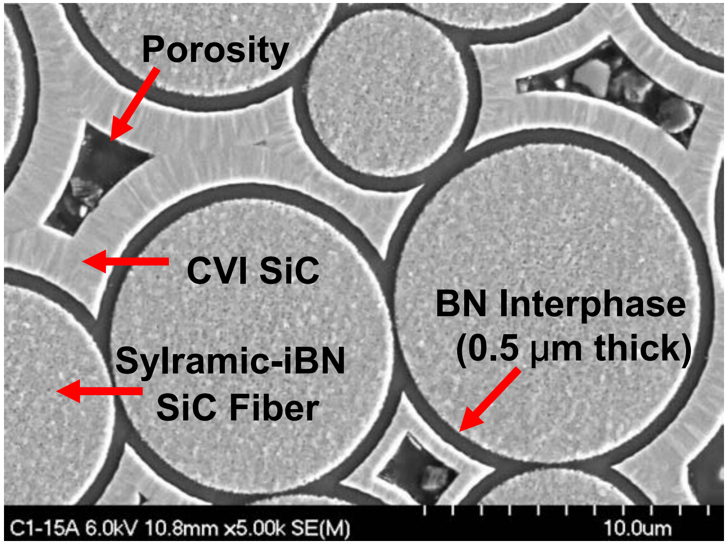
3000°F SiC/SiC for Leading Edges

Objective: Develop durable 3000ºF SiC/SiC structural elements

Silicon carbide fiber reinforced material offers improved oxidation resistance over carbon fiber materials.

Extend creep resistance to >2700ºF through material processing modifications and heat treat cycles for enhanced thermal conductivity and creep resistance.

Establish relationship between mechanical performance, material microstructure and non destructive investigations to improve component design capability.



Microstructure of Sylramic-iBN SiC Fiber-Reinforced CVI SiC CMC

Component Life is defined by TIME, TEMPERATURE, and LOAD: for short duration EDL type missions use temperature may be >3000ºF.

Advanced UHTC Development

UHTC properties for TPS applications

- Thermal conductivity
- Fracture toughness/mechanical strength
- Oxidation resistance

Property trade space

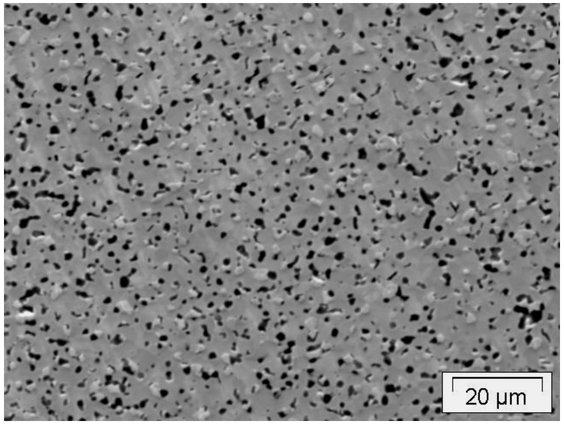
- Tailor microstructure through composition, additions and processing

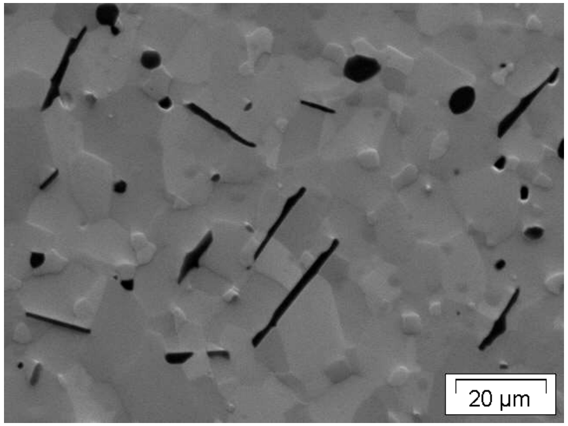
Approach 1: Morphology

- High-aspect-ratio grains
- Growing SiC acicular grains

Approach 2: Ductile Grain boundary phases

- Compare hot-pressing process to Spark Plasma Sintering over range of conditions





Baseline UHTC microstructure (HfB_2-20%SiC)hot pressed with baseline schedule

Experimental Methods

Objective

Improve design component life through quantified techniques relating NDE methods to microstructure and residual life.

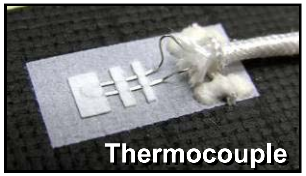
Establish high fidelity testing techniques for characterizing design-critical behavior of high-temperature materials for improved design analysis capability.

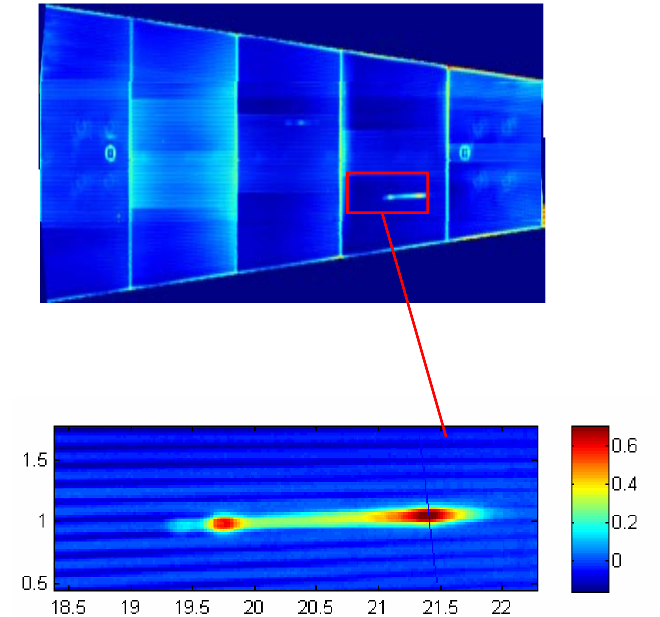
Develop imbedded sensor technology for CMC components.

Technical Challenge

Develop validated non-destructive evaluation (NDE) technology to distinguish and quantify material defects and damage that support re-usable life assessment.

Develop advanced structural sensors, such as strain, temperature, heat flux, and acceleration, for operation at extreme temperatures and environments.





NDE Images of a Haynes 188 Nozzle Side Panel for the DCR

Non-Destructive Evaluation Techniques

NDE of Coated C/Sic Materials

Performed NDE on C/SiC before and after exposure to simulated Falcon HCV-OS/HTV-3 mission environment. Detected global and localized damage in the specimens after MMSF mission exposure.

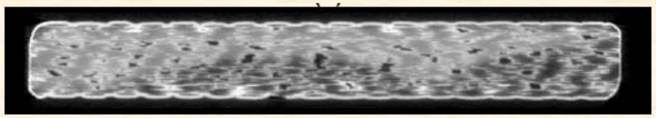
NDE of CDP-I Metallic

Designed, fabricated and tested hardware and software for NDE scanning of DCR before and at intervals during testing. Preliminary measurements show ability to detect simulated cracks.

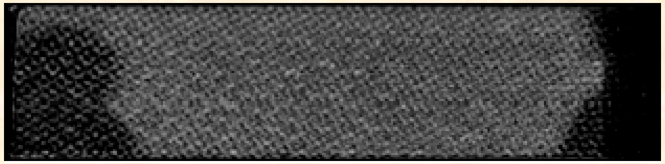
NDE of SiC/SiC Materials

NDE characterization of SiC/SiC using baseline specimens begun. Fabrication of SiC/SiC NDE standards panel for defect type validation study initiated.

CT Cross Sections
Both Are Post-Exposure

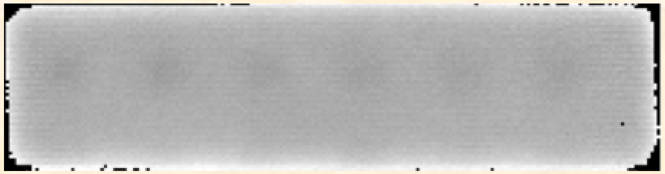


Cross-Ply Cut

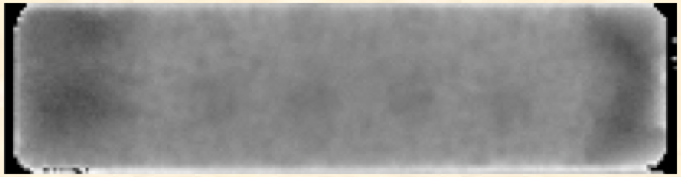


Cut Parallel to plies

Thermal Diffusivity Images



Before Exposure



After Exposure

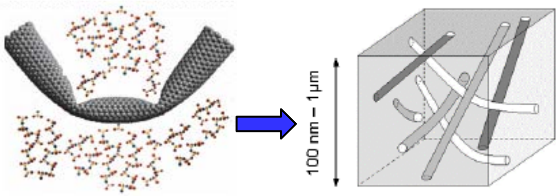
Dark Indicates Lower Density Areas

NRA Solicitations

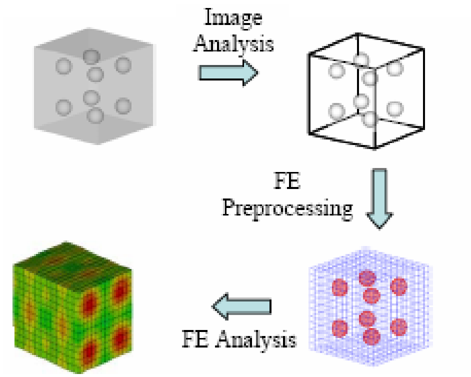
Objectives:

- NASA will advance the state of knowledge of the underlying physics and its modeling by partnering with universities and companies engaged in foundational research.

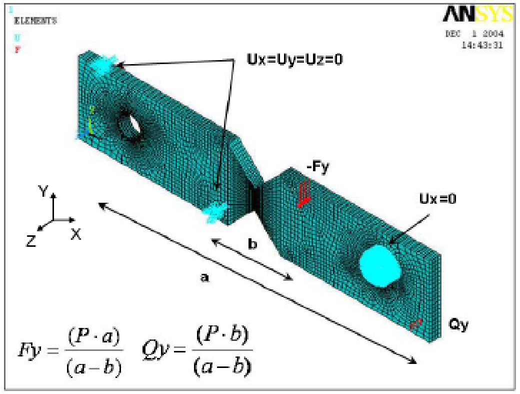
- NASA will investigate discipline-related challenges and will interact with the aeronautics community to explore innovative solutions.



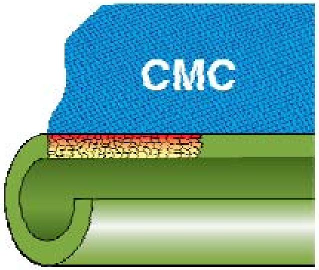
Multi-scale Models



Process Modeling



Testing Standards



Multifunctional Materials

2006 NRA Efforts

Advanced Ablators	Advanced computational tools that will enable predictive modeling and design of nano-structured multifunctional phenolic ablator materials for light-weight thermal protection of HMMES vehicle systems.
Creep Resistant Titanium	Process modeling capability to enhance beta formation routes for titanium alloys
High Temperature CMC	Low cost processing technique to fabricate a cost-effective, high strength and oxidation-resistant carbon fiber-reinforced composite for ultrahigh temperature TPS applications
Integrated Thermal Protection	Design, fabricate, and test a multi-functional load-bearing acreage thermal protection system structural concept for will reduce airframe weight and increase safety of current or future vehicles
Life Prediction	Generate finite-element based models for predicting life expectancy of carbon-fiber reinforced silicon carbide ceramic composites
Test Methods	Validated test techniques that enable the measurement of material properties for ceramic matrix composites that are critical to predicting elevated temperature performance.
High Fidelity Analysis	Advance the computing capability in the area of nonlinear reduced-order structural response analysis as it applies to hypersonic flight regime and vehicle structures
Validated NDE Methods	Develop non destructive evaluation methods capable of identifying and quantifying ceramic composite defects and develop analytic models capable of predicting effects on material behavior

2007 HRRLS NRA Efforts

High Temperature Sensors	Comprehensive review of performance, manufacturing capabilities, and technology readiness of current sensors and sensory materials.
Structurally Integrated TPS	Develop rigid honeycomb insulation concepts for structurally integrated thermal protection systems.
Physics-Based Models	Establish a stochastic, hierarchical textile model based on fabric topology to model CMC property variations.
Multifunctional Materials	Develop a high temperature thermal electric system that is compatible with silicon-based composite systems for application at 2000°F
CMC Database	Assessment of the manufacturing capability, scale-up readiness, design readiness of high temperature composite.
Cool CMC Structures	Develop a fabrication process of functionally graded, hydrogen impermeable coatings for ceramic-metal composite heat exchangers.
Durable Materials	Investigate new UHTC coating systems for ceramic composites for extended life of reusable components.

2007 HMMES NRA Efforts

Durable Ballutes	Develop a fiber reinforced seams and joint concepts for inflatables
Ballute Materials	Assess capability of current fabric bladders, adhesives, and thin film materials technology for high temperature ballute applications.
Advanced Ablators	Develop processing techniques for producing for dual layer, multifunctional phenolic and silicone ablators.

Summary Remarks

NASA FA Hypersonic project is focused on tool and technology development required to enable airbreathing access to space and high mass Mars entry

Significant effort refocusing on foundational, discipline, and multi-disciplinary research

- Integrated analysis and design tools
- Physics-based material modeling and lifing tools
- Advanced Structural Concepts
- Advanced lightweight ablator materials
- Improved high-temperature materials
- Sensors and sensory materials